

**Supporting Information for**  
**Analysis of the Global Warming Potential of Biogenic CO<sub>2</sub> Emission in Life**  
**Cycle Assessments**

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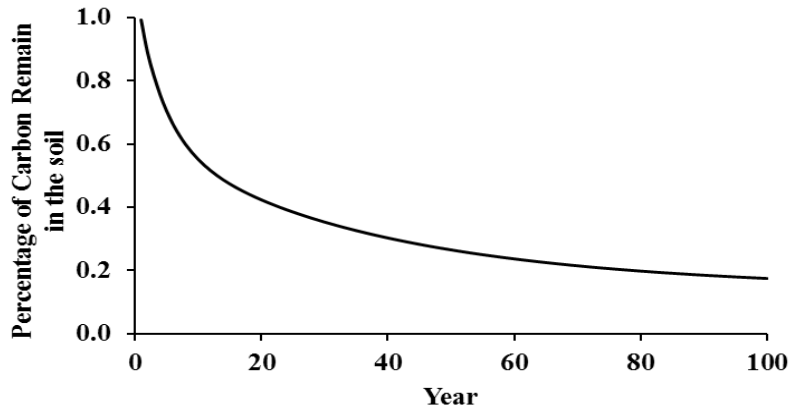
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## Decomposition of residue

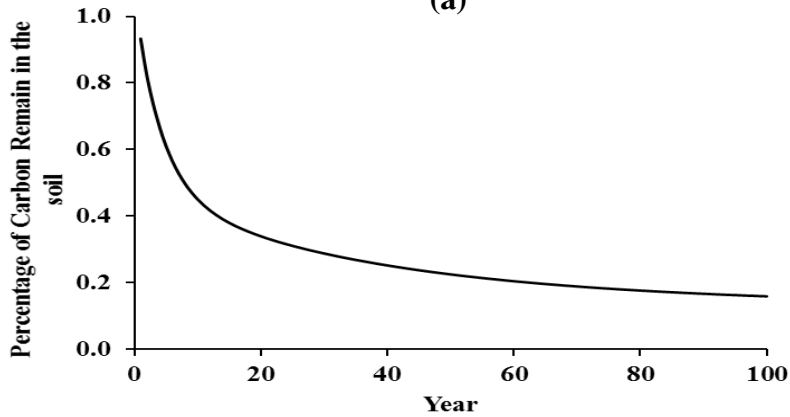
Soil carbon model Yasso07 was used in this study to simulate the decomposition of residues (Tuomi et al. 2009). The parameter values were set by Liski et al. (2009). The decomposition rate of soil carbon inputs depends on chemical compartments of inputs which were also determined by the average of chemical composition of residue types (Liskiet al. 2009). The detailed chemical composition of leaf/needle and branch/stem/root is listed in table S1. Fig. S1 shows the decomposition rate of leaf/needle and branch/stem/root within 100 years.

Table S1. Chemical composition of residue types.

Type	Acid hydrolysables	Water solubles	Ethanol solubles	neither soluble nor hydrolysables
Leaf/needle	45%	24%	9%	22%
Branch/stem/root	52%	2%	6%	40%



(a)



(b)

Fig. S1. The decomposition rate of residue simulated by Yasso07: (a) branch/stem/root; (b) leaf/needle.

### Setting of mass allocation

The total emissions ( $E_{total}(t)$ ) remain in the atmosphere are from four compartments: biomass combustion ( $E_b(t)$ ), soil carbon decomposition ( $E_s(t)$ ), long-lived woody products ( $E_{wpl}(t)$ ) and short-lived woody products ( $E_{wps}(t)$ ).

$$E_{total}(t) = E_b(t) + E_s(t) + E_{wpl}(t) + E_{wps}(t) \quad (S-1)$$

The mass allocation coefficient of removed biomass ( $\sigma_b(t)$ ) is calculated based on the CO<sub>2</sub> emissions remained in the atmosphere in each year. Thus,

$$\sigma_b(t) = \frac{E_b(t)}{E_{total}(t)} \quad (S-2)$$

The decay rate of CO<sub>2</sub> emissions is not following a simple line. The fraction of its initial pulse of CO<sub>2</sub> at time  $t$  is labeled as  $y(t)$  which is calculated by the equation (1) in the main manuscript. Thus,  $E_b(t)$  is calculated as:

$$E_b(t) = \omega(B - T) \cdot y(t) \quad (S-3)$$

Where  $\omega$  is the proportion of residues that are collected for bioenergy.  $B$  is the amount of biomass in tC/ha before harvest and  $T$  is merchantable timber in tC/ha.

$$\begin{aligned} E_s(t) &= \int_0^t [E_l(t') + E_{nl}(t')] \cdot y(t - t') dt' \\ &= \int_0^t [p_l(B - T)d_l(t') + (1 - p_l - \omega)(B - T)d_{nl}(t')] \cdot y(t - t') dt' \\ &= \int_0^t [p_l d_l(t') + (1 - p_l - \omega)d_{nl}(t')] (B - T) \cdot y(t - t') dt' \end{aligned} \quad (S-4)$$

Where  $E_l(t)$  is emission from leaf, and  $E_{nl}(t)$  is emission from branch, stem and root.  $p_l$  is the percentage of leaf in remain biomass after harvest.  $d_l(t)$  is decomposition rate of leaf, and  $d_{nl}(t)$  is decomposition rate of branch, stem and root.

$$E_{wps}(t) = \begin{cases} 0, & t < L_s \\ \eta_s T y(t - L_s), & t \geq L_s \end{cases} \quad (S-5)$$

$$E_{wpl}(t) = \begin{cases} 0, & t < L_l \\ \eta_l T y(t - L_l), & t \geq L_l \end{cases} \quad (S-6)$$

Where  $L_s$  and  $L_l$  are the life span of short-lived and long-lived woody products.  $\eta_s$  and  $\eta_l$  are percentage of short-lived and long lived woody products in the total merchantable timber.

In this study, we assumed  $p_l$ ,  $\eta_s$ ,  $\eta_l$  are 10%, 70% and 30% respectively. Two scenarios were studied: worst case ( $\eta_l = 0\%$ ) and best case ( $\eta_l = 100\%$ ). The mass allocation coefficient ( $\sigma_b(t)$ ) is shown in Fig. S2. To simplify the model, the life span of life-lived woody products is

set to 100 years to ensure that it is longer than  $RL$ , where  $RL$  is rotation length. The short-lived woody product will emit  $\text{CO}_2$  right after harvest.

When the residue is not removed, the mass allocation coefficient of this amount of residue ( $\sigma_d(t)$ ) is calculated in the same by replacing  $E_b(t)$  with  $E_d(t)$ , where  $E_d(t)$  is:

$$E_d(t) = \int_0^t \omega(B - T)d_{nl}(t') \cdot y(t - t')dt' \quad (S - 7)$$

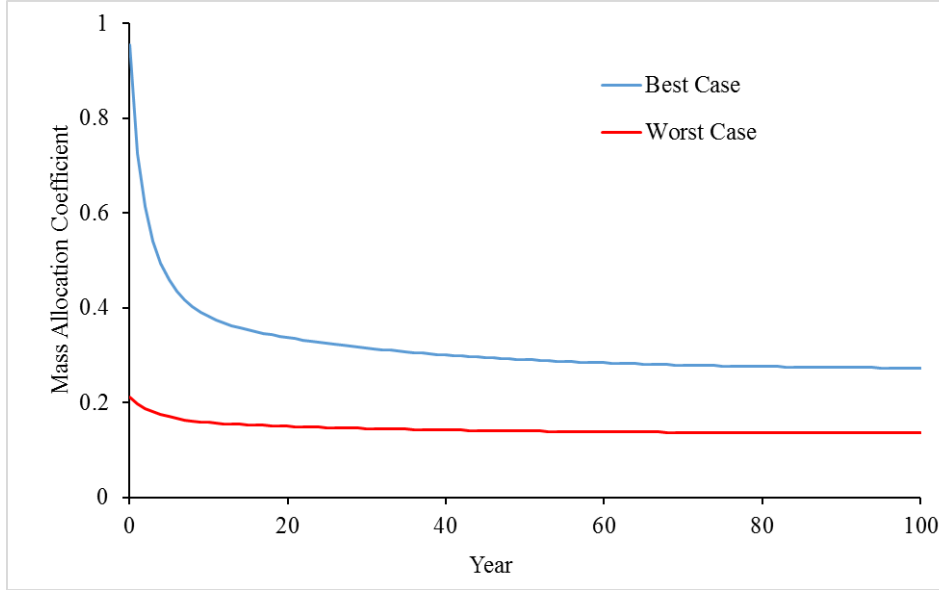


Fig. S2. The mass allocation coefficient in the two scenarios.

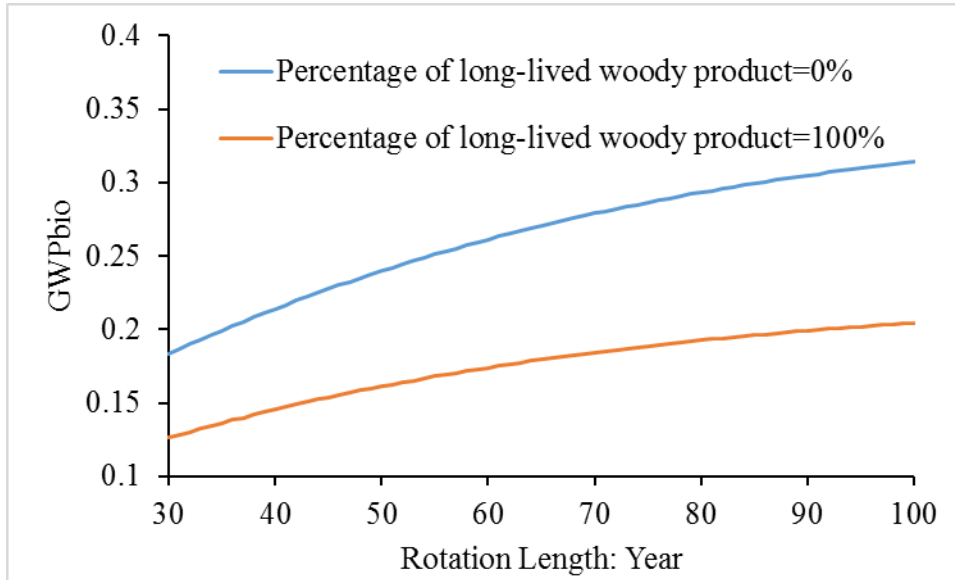


Fig. S3. The sensitivity analysis of rotation length for  $\text{GWP}_{\text{bio}}$ .

## Sensitivity Analysis

Two major factors need to be tested for sensitivity: rotation length ( $RL$ ) and percentage of long-lived woody product ( $\eta_l$ ). The sensitivity analysis of rotation length from 30 years to 100 years is shown in Fig. S3. The growth function of forest with different rotation length were obtained by change the setting of the Chapman-Richards growth model. Because there is no way to validate the settings of the parameters, this sensitivity analysis can only be considered as a reasonable approach. The results of sensitivity analysis of  $\eta_l$  showed a linear correlation between  $GWP_{bio}$  and  $\eta_l$ . Thus, the  $GWP_{bio}$  for certain  $\eta_l$  can be easily obtained by two extreme scenarios ( $\eta_l = 0\%$  and  $\eta_l = 100\%$ ), and no table and figure is provided in the Supplemental Information.

## System boundary of LCA case studies

Five cases were included in this study: biomass to ethanol, biomass to liquid fuel via fast pyrolysis, coal and biomass to liquids, biomass to bio-power and biomass to pellet fuel. The cradle to grave assessment include collection, transportation, storage, preprocessing, bio-product conversion, distribution, final usage and waste disposal. The detailed system boundaries are shown in Fig. S4-S7.

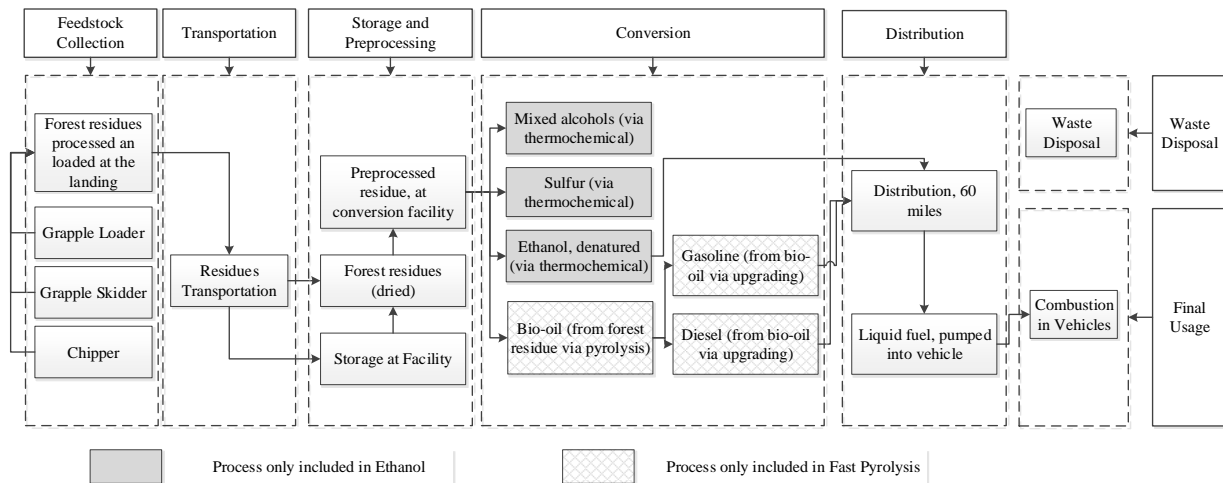


Fig.S4. System boundary of biomass to ethanol and biomass to liquid fuels via fast pyrolysis.

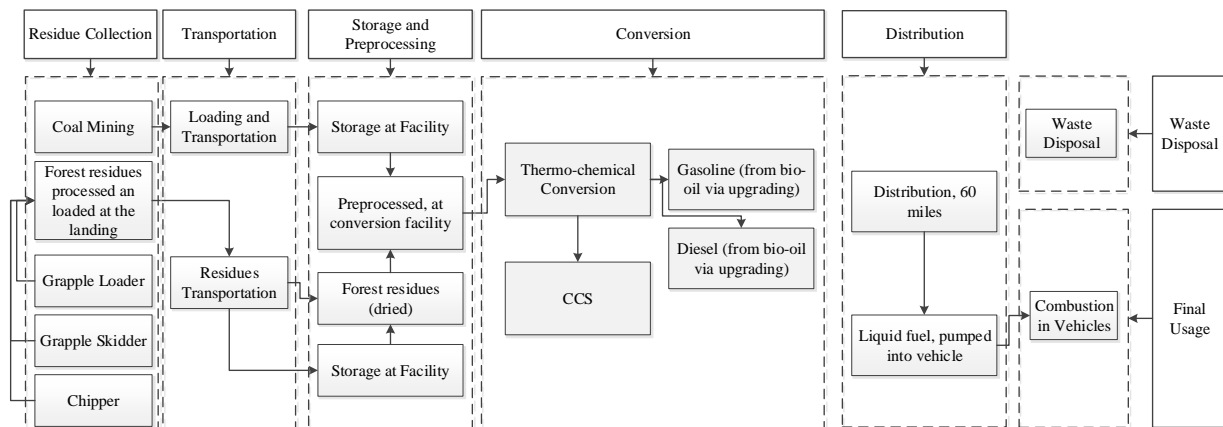


Fig.S5. System boundary of coal and biomass to liquids.

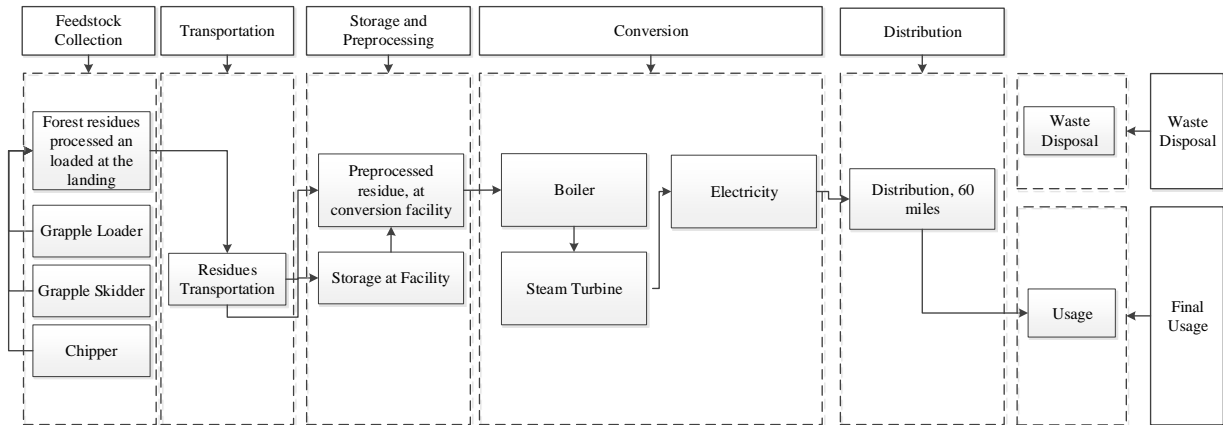


Fig. S6. System boundary of biomass to bio-power.

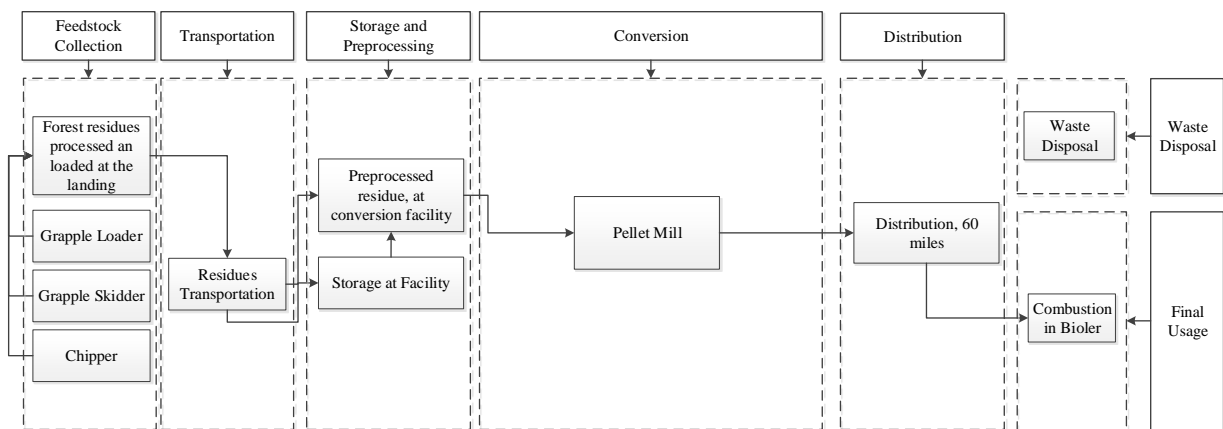


Fig S7. System boundary of biomass to pellet.



## Life cycle inventory

The detailed data sources for the inventory data are listed in Table S2.

Table S2. Source of life cycle inventory data.

Processes	Biomass to Ethanol	Biomass to Liquid Fuel via Fast Pyrolysis	Coal and Biomass to Liquids	Biomass to Bio-power	Biomass to Pellet
Feedstock Collection	Wu <i>et al.</i> 2012	Wu <i>et al.</i> 2012	Wu <i>et al.</i> 2012; US LCI.	Wu <i>et al.</i> 2012	Wu <i>et al.</i> 2012
Transportation	Ecoinvent 3.	Ecoinvent 3.	Ecoinvent 3.	Ecoinvent 3.	Ecoinvent 3.
Storage and Preprocessing	Emery and Mosier 2012; US LCI; Idaho National Laboratory Process Demonstration Unit	Emery and Mosier 2012; US LCI; Idaho National Laboratory Process Demonstration Unit	Emery and Mosier 2012; US LCI; Idaho National Laboratory Process Demonstration Unit	Emery and Mosier 2012; US LCI; Idaho National Laboratory Process Demonstration Unit	Emery and Mosier 2012; US LCI; Idaho National Laboratory Process Demonstration Unit
Conversion	Hsu 2010	Hsu 2012	WVU Chemical Engineering lab simulation	Spathet <i>al.</i> 1999	INL PDU
Distribution	Marano and Cifernro 2001	Marano and Cifernro 2001	Marano and Cifernro 2001	Marano and Cifernro 2001	Marano and Cifernro 2001
Final Usage	Hsu 2010	Hsu 2012	WVU Chemical Engineering lab simulation	-	Brassard <i>et al.</i> 2014
Waste Disposal	Ecoinvent 3.	Ecoinvent 3.	Ecoinvent 3.	Ecoinvent 3.	Ecoinvent 3.

### Change of forest carbon

Traditional LCA quantifies the emissions relate to the production of bioproduct and harvest of biofuels. Forest carbon change due to the collection of biomass should be included.

$$FC_b = GWP_d E'_s(t) \cdot \frac{\omega(B - T)}{\omega(B - T) + T} \quad (S - 8)$$

$$E'_s(t) = \int_0^{t^{comp}} [p_l(B - T)d_l(t') + (1 - p_l - \omega)(B - T)d_{nl}(t')]dt' \quad (S - 9)$$

Where  $t^{comp}$  is the year when the emission from soil organic matter is fully compensated by forest regrowth.  $GWP_d$  is calculated as formula (8) in the manuscript. The  $GWP_d$  is shown in Table S3. To calculate the LCA emissions,  $3.667GWP_d \cdot FC_b$  should be add to the total LCA GHG emissions. A coefficient 3.667 is multiplied to convert tC to ton CO<sub>2</sub> eq.

Table S3.  $GWP_d$  values for different cases.

Rotation: years	$GWP_d$	
	$\eta_l = 0\%$	$\eta_l = 100\%$
30	0.07	0.04
50	0.10	0.07
100	0.12	0.09

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